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Late Holocene Episodic Aeolian Activity and Landscape Development in the Cimarron River Valley; Western Oklahoma

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Introduction

The major rivers of Western and Central Oklahoma are shallow sandy streams that flow generally northwest to southeast. Throughout the Quaternary these rivers have been migrating down a shallow regional slope towards the southwest (Madole *et al*., 1991). In the process the rivers leave a sequence of terraces to the northeast while reworking older terrace deposits of antecedent systems. Overprinted on this fluvial staircase is an aeolian record of dune formation and migration that reflects regional changes in sediment supply and drought. The resulting landscape is geomorphically dynamic and geochronologic-ally complex.

The Cimarron River valley is a major feature of western Oklahoma. It enters the state from Kansas and flows to its junction with the Arkansas River. In the study area, the valley averages 40 to 50 kilometers wide, but only about 50 meters in elevation from valley floor to the north divide. On the north side of the river, ten fluvial terraces mantle the valley wall from the flood plain to the divide between the Cimarron River and the Salt Fork of the Arkansas River.

Aeolian activity within the valley of the Cimarron River in western Oklahoma has been an important factor in the development of the present landscape. Aeolian landforms such as dune fields and sand sheets are extensive on the north and east sides of the river where they mantle all or part of each of the terraces. Previous work established a variety of ages for dunes in the area and showed the consistency of the prevailing winds since the end of the Pleistocene, but did not establish a chronology of aeolian activity or study the episodic development of the aeolian landforms on the landscape.

Since significant aeolian activity is negligible in the current climate, we assume that the aeolian features are a product of past arid episodes. Historical records are lacking in Oklahoma, but records from Kansas indicate intense arid episodes in the 1800s (Muhs and Holliday, 1995). A large body of work exists that shows aridity as a recurring feature of the Holocene.

In Southeastern Major and Northwestern Kingfisher counties in Oklahoma a sequence of Quaternary terraces of the Cimarron River has been identified which includes eight distinct terrace levels (Scott, 1999). Field observations in this area have indicated that the ridge dune on the second terrace level above the flood plain of the river (Qt2) contains a record of middle to late Holocene environmental change (Scott, 1999).

This paper uses a multidisciplinary approach including geomorphic surface mapping, soil/stratigraphic analysis, radiocarbon dating and OSL dating to investigate the chronology of soil formation and aeolian activation periods recorded in the Qt2 ridge dune deposits as well as the rates of sediment accumulation and the spatial variability of aeolian processes during active aeolian episodes. These studies show that aeolian landforms superimposed on fluvial terraces adjacent to the Cimarron River in Major County are the product of distinct climatic conditions, in which periods of dune activity are episodic and accumulation of sediments is relatively rapid. Soil forming processes operated on the stabilized dunes during intervening wetter/cooler periods. We also demonstrate that the synthesis of geomorphic techniques, soil stratigraphy, ^{14}C dating, and advanced OSL dating can provide high-resolution pictures of aeolian activity in the Southern Plains.

Methods

Geomorphic Methods

Surface Mapping: The geomorphic surfaces of 400 km^2 in eastern Major County were mapped in the field at 1:24,000 scale. Field observation, aerial photography, USDA-NRCS soil survey maps, and USGS topographic maps were used as resources to identify terraces, dune fields, and sand sheets. The mapped area extends from the Cimarron river flood plain (T0) up to the Qt8 terrace level. Two sites, Hanor and Hajek farms, were selected for intensive investigation. These two sites of about 40 ha are about 5 km apart; both are on the ridge dune complex that sits on fluvial terrace Qt2.

Dune morphology: In the study area dune type, size, slope, weathering, soil development, and vegetation vary in a progressive manner with distance from the river. Parallel ridge dunes, mostly <3m high, occur on the flood plain. On the Qt1 terrace, the small dunes are consolidated into a large, steep ridge dune, with occasional blowouts transformed into parabolic dunes. Dunes on the Qt2 terrace surface have been modified by northwest winter winds into large parabolic dunes, however, prominent ridge dune complex remains on the escarpment rising to the Qt2 terrace. Dunes on the Qt3 to Qt7 terraces are progressively more complex, with gentler slopes and more strongly developed soils.

Soil Stratigraphy

Twenty-one soil profiles were selected for sampling to represent soils from all the landforms and geomorphic positions in the study area. A truck-mounted Giddings probe was used to extract the soil cores. Soils were described to the standards of Schoenberger et al. (1998). Buried surfaces, truncated soil sequms, indicators of age and weathering, and depositional features were of particular interest in developing the soil stratigraphy. The cores were also used to identify profiles and horizons for radiocarbon and OSL dating.

Geochronologic Methods

Relative chronology techniques: In the study area, several characteristics associated with the dunes provide information to rank the dune formations from youngest to oldest. Vegetation, depth of weathering, development of the soil profile, dune pattern, position, distance to the sand source, and dune morphology all give clues to the relative age and relationships of the major dune fields. During preparation of the geomorphic surface map, these characteristics were inventoried and used to support the correlation. The types of dunes, abundance of each type, slope, shape, and height were also noted. Percentage of ground cover and percentage of the dune field cultivated were estimated from aerial photos and inventoried.

Radiocarbon Dating: Three samples were selected for radiocarbon dating. At the Hanor site a ^{14}C sample was taken from the a buried soil horizon developed in fluvial deposits of the Qt2 terrace to provide a limiting age for the start of aeolian deposition on the terrace. Two additional ^{14}C samples from higher stratigraphic positions within the Qt2 ridge dune complex, representing a later Holocene soil forming period, were also collected – one at the Hanor site and one at the Hajek site.

About 500 grams of each sample (bulk SOM) was submitted to Beta Analytic labs in Miami, Florida. After pretreatment the remaining carbon was reduced to graphite and dated by accelerator-mass-spectrometer (AMS) ^{14}C measurement. Analysis (by Beta Analytic) included calendar calibration and isotopic correction.

OSL dating: Seven samples for OSL dating were collected from backhoe pits in four dunes in the Qt2 terrace ridge dune complex. Samples were taken from C soil horizons with intact primary sedimentary structure (low angle cross bedding). All sample preparations were carried out under subdued lighting. Dating measurements were conducted on surface-etched quartz grains from the 125-150μm fraction using a Risø DA-15 automated OSL/TL reader. Both green-light (526±□ nm) and blue-light (470±30 nm) stimulation were used. The resulting OSL signal was measured in the UV emission range (340Δ80 nm).

Single aliquot regeneration (SAR) procedures were used to determine a set of equivalent doses (D_e) for each sample (Murray & Wintle, 2000). D_e data sets ranged in size from 48 to >100 determinations per sample. In addition to the standard SAR calibration procedures, an additional "check dose" was used with each aliquot to monitor the success of the method in recovering a known dose and to represent the integrated error associated with the measurement and calibration process (Lepper, 2001).

Individual dose rates for the samples were calculated from the concentration of the radioisotopes of K, Rb, Th and U and their daughters in each horizon plus the cosmic ray dose at the sample depth. All dose rate inputs were adjusted for average water content which was taken to be 4 ±1 %. Elemental concentrations of K, Rb, Th and U were determined at The Ohio State University Research Reactor by instrumental neutron activation analysis (INAA).

Synopsis of Results

The results of this investigation, which will be presented in much greater detail at this meeting (ICAR5, Lubbock TX, July 2002) and in a forthcoming paper, are summarized below:

- The buried soil formed in fluvial materials at the base of the Hanor section represents an extended late Pleistocene / early Holocene soil forming period (^{14}C date: 12.8-11.5 ka BP) and can be correlated to a regionally extensive paleo-surface known as the Brady soil.
- The Brady surface is overlain by aeolian deposits from at least one middle Holocene event dating to ~3.3 ka BP, the oldest OSL age at the Hajek site.
- ^{14}C dates from the higher stratigraphic positions within the dunes at Hajek and Hanor farm indicate dune stability and soil formation between 1200 and 1600 yr BP.
- The latest period of aeolian activity began after 1000 yr BP and ended after 750 yr BP (abundant OSL ages between 775-865 yr BP)
- The modern soil formed on the Qt2 dune complex is consistent with formation times less than 500-1000 years, which is in agreement with the OSL dates for the most recent remobilization period.
- OSL dates from the Hajek site indicate a truncation in the profile that was not apparent in the soil stratigraphy -- highlighting a potential added benefit of OSL dating for aeolian field studies.
- At these sites, advanced OSL dating methods produced stratigraphically consistent ages without exception, permitting "net" depositional rates to be calculated (1.1-1.4 cm/yr).
- The color of soils developed in aeolian sands has been used in some locations as an indicator of age. In this area, soil color (variation in redness) was not an effective temporal indicator. The Buckminster dune was virtually the same age as the dunes at the Hajek site, but much redder.

Conclusions

The chronology of events recorded in the aeolian deposit on the Qt2 terrace of the Cimarron River in West-central Oklahoma is consistent with regional paleoclimate variations in the Osage Plains reported by Hall (1988). The aeolian activity period between 750-900 yr BP appears to be consistent with observations throughout the Great Plains (Arbogast, 1996; Muhs et al., 1996, Stokes and Swinehart, 1997, and others). Results of this investigation also suggest that the drought reflected in these deposits started earlier in Southern Plains (OK, KS) than in the Northern Plains (NB).

At these study sites ^{14}C and advanced OSL dating methods produced coherent and complimentary results at a greater temporal resolution than radiocarbon dating by itself could have achieved. Combining geomorphic methods, soil/stratigraphic descriptions, radiocarbon and OSL dating methods enabled us to achieve a high-resolution picture of aeolian activity at these sites.

The success of the integrated methods and multidisciplinary approach used in this investigation opens the door for extended study in this area. An analysis and sampling transect across progressively

higher and older terrace dune complexes could help decipher migration and entrenchment rates for the Cimarron River in Western Oklahoma, as well as reveal other locally and regionally significant climatic events.

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